2. PROGRAM SCOPE AND DEFINITIONS

By John G. Lowry

NASA Langley Research Center

INTRODUCTION

The purpose of this paper is to review briefly the objectives and history of the NASA Acoustically Treated Nacelle Program and provide a background for the contractors' presentations of the final results of their studies.

The main objective of the program was to identify promising nacelle modifications for current four-engine turbofan-powered transports that would reduce the noise under the approach path by 15 PNdB. Another equally important objective was to develop acoustic treatment technology that would be applicable to other turbofan engines including the newer high-bypass-ratio engines. Certain design constraints were placed on the modifications since they were to be considered for application to commercial transports. Although it was anticipated that the devices would provide relief during take-off and climbout, under no conditions should the modifications increase the already undesirably high take-off noise. It goes without saying that there should be no compromise in flight safety. There should be no increase in crew workload during the critical approach phase of flight because the safety of operations would be affected. Last but not least, the modified airplane must retain its economic viability. The problem then was one of designing a modification to the nacelle that was practical, that could reduce the approach noise by a substantial amount, that would have as small performance penalties as possible, and one that could be manufactured and installed at a reasonable cost.

DISCUSSION

The procedure followed by the contractors in developing the modifications was to develop the several concepts through basic experiments of acoustic materials, component test of treatment concepts, and inlet and duct design. As a result of these studies, the more promising concepts were to be tested by use of the ground runup technique to evaluate or substantiate the acoustic and engine performance of the modified nacelle within the actual engine environment. The most desirable of these concepts, from both an acoustic and economic point of view, would be selected for flight testing on a transport airplane since the desired information is the noise measured under an actual airplane in flight. In addition, this procedure allowed for measurements of performance with the modified nacelles installed on the airplane. Each of the contractors was required, in addition to taking physical measurements of the noise reduction, to obtain data on the subjective reaction of people to the nacelle modification.

The project was started in May 1966 as part of the NASA's contribution to the Interagency Aircraft Noise Abatement Program. It should be pointed out that this project is only a small part of the overall NASA acoustical research program. A request for proposal was sent to industry in September 1966. After reviewing the proposals submitted, negotiations were started with The Boeing Company and the McDonnell Douglas Corporation; as a result, contracts were signed with the two companies in May 1967. The studies were to be conducted in such a manner that the data would, in addition to defining nacelle modifications applicable to the current four-engine transports powered by JT3D turbofan engines, provide technology that would be applicable to other turbofan engines. In October 1968, a status report on these studies was presented to industry as part of NASA's progress report of research related to noise alleviation of large subsonic jet aircraft. The papers presented at that time were published in NASA SP 189 (ref. 1). At that time they reported in detail on the results of their studies including the results of the full-scale ground runup tests of promising concepts on a JT3D engine. They also presented a description of the treated nacelles selected for flight testing. Since that time, they have each fabricated four treated nacelles, installed them on test airplanes, and performed the flight tests necessary to obtain the acoustic and performance characteristics of the modified airplanes. The flight tests of the treated airplanes were made during March and May, 1969. The results of the flight tests have been analyzed and papers 3 to 13 herein present a summary report on the final results of the contractors' $2\frac{1}{2}$-year effort.

Figures 1 to 3 are presented to indicate the noise sources and their relative strengths and to indicate why the program was directed toward the approach noise. Figure 1 indicates the sources of noise radiated from a turbofan engine. The fan noise is radiated forward through the inlet and aft through the fan discharge duct. The jet noise is generated from the turbulance aft of the discharge nozzle. The main source of jet noise is that emitted from the primary nozzle. Because of the sound intensities generated and the various directivity patterns developed by these noise sources, the total noise heard at any point under an airplane flight path is a complex combination of both fan and jet noise. The effort of this program was limited to reducing the fan noise radiated from the inlet and fan discharge ducts.

Figure 2 shows the relative contribution of each of the noise sources to the total noise as heard by an observer during an airplane flyover and illustrates one of the reasons that the program was directed toward reducing the fan noise. The perceived noise level (PNL) under the flight path of a four-engine transport is presented as a function of the thrust. It can be seen that at the higher thrusts, associated with take-off operations, the fan noise emitted from the fan discharge duct is the controlling factor and would have to be reduced if any reduction in take-off noise is to be obtained. At thrusts associated with landing approach, the fan noise is about 18 PNdB above the jet noise. This analysis

indicated that a noise suppression goal of 15 PNdB was feasible by suppression of fan noise only, less reduction being needed in the inlet noise than in the fan discharge noise. Because many of the complaints around airports occur in this landing phase of operation, substantial benefits for the airport neighbor appeared possible through attenuation of the fan noise in the approach power region.

The type of noise spectrum under consideration is illustrated in figure 3, which is a plot of sound pressure level (SPL) in dB as a function of frequency in hertz. This spectrum is typical for the JT3D engine during landing approach. Not only is the fan noise level of higher intensity than the jet noise, but it also occurs in a higher frequency region. The characteristic high-pitched whine associated with the turbofan engine at landing thrust is indicated by the spikes at about 2500 Hz and higher. Suppression of these high-frequency spikes would reduce the overall noise level as well as alleviate the undesirable fan whine. On the basis of this possibility of noise reduction, the program was directed toward reduction of fan noise during landing approach.

During the negotiations of the contracts with Boeing and McDonnell Douglas, it was decided that the overall value of the program could be enhanced by having the two contractors take different approaches to the problem and have different goals of attenuation. The McDonnell Douglas approach was limited to configurations using treated inlets. At that time it was felt that the use of treated inlets would limit the attenuation to about 7 to 10 PNdB and, as a result, the McDonnell Douglas goal was set at that value. In order to match the fan discharge duct with the inlet, they were also restricted to short fan discharge ducts. Figure 4 is a photograph of the McDonnell Douglas treated nacelle. Some of the treatment in the inlet can be seen and the fan nozzle is located about halfway back on the nacelle. The term short fan discharge duct means that the duct ends well ahead of the jet nozzle. Details of the nacelle configuration and the acoustic treatment are given in paper 3 herein. In addition to the physical measurements of noise, provisions were made to obtain additional noise tapes during the flight tests that could be used in the laboratory to study the subjective response of a jury of college students to the noise of the airplane before and after the installation of the treated nacelles. The modification selected for flight test was to be installed on a Douglas DC-8 airplane.

The original noise reduction goal of 15 PNdB was retained for the Boeing portion of the overall program. To obtain this amount of attenuation, it was believed that the more effective sonic or near-sonic inlet concept would be required to reduce the inlet noise to the desired level. The operation of a sonic inlet is described in detail in paper No. 13 of reference 1. To obtain the higher attenuation, Boeing was required to develop a long fan discharge duct in order to get the required amount of acoustic treatment and thus reduce the aft radiated fan noise by 15 PNdB. During the first year's effort, McDonnell Douglas's work on the treated inlet concept indicated substantially greater noise reduction than at

first thought possible. Because of these promising results and Boeing's success with the long duct, the Boeing contract was modified to defer flight testing of the sonic inlet and substitute flight tests of a treated inlet. Figure 5 is a photograph of the Boeing treated nacelle. As in figure 4, a little of the treatment in the inlet is shown and the fan discharge is located at the aft end of the nacelle, almost coplanar with the jet exhaust nozzle. Details of the configuration and the acoustic treatment are given in paper 6 herein. Since the fan ducts extend to the aft end of the nacelle, they are referred to as long ducts. The change was made from a sonic to a treated inlet to make the data available on a more timely basis and to get results on a mechanically simpler inlet. As in the Douglas program, Boeing was to obtain subjective evaluations of the modification as well as physical measurements of the noise. For their subjective program, Boeing obtained the data in the field by having a jury of about 190 people, under and to the side of the flight path, make their judgments based on actual airplane flights. The noises were recorded so that laboratory studies could also be made at a later date if desirable. Boeing was to use a Boeing 707-320B airplane for the flight tests required to evaluate the treated nacelle.

In order to complete the reporting of the Boeing program, a few remarks on the work done on the sonic inlet since the conference of a year ago seems to be in order. Boeing completed the fabrication of the inlet equipped with the automatic control device that adjusted the inlet area, and thus the Mach number in the inlet, as a function of the fan rotational speed. This device was tested in conjunction with the treated long fan discharge duct to obtain the acoustic characteristics of the combination. In addition, tests were run to evaluate the relatively simple control device and determine how well it would operate under rather severe engine accelerations, in cross winds, and under normal throttle movements. It is expected that the final results of the Boeing contract will be obtained in the early part of 1970. It is sufficient to say that the results indicate that the sonic or near-sonic inlet could be made into a satisfactory inlet for a subsonic transport.

The contractor presentations will refer to several noise terms that need to be defined. Sound pressure level (SPL) is the term generally used to define the level of noise and is expressed in decibels (dB) and is referred to the conventional value of 0.0002 dynes/cm^2. A decibel is a logarithmic unit and represents the smallest perceptible change in amplitude of a sound: A 6-dB change represents a factor of 2 in sound pressure. One of the subjective measurements of noise that has wide acceptance is that of perceived noisiness. Perceived noise level (PNL) is a function of the sound pressure level plus a spectrum shape factor that reflects the reaction of people to noise. This shape factor weights the various frequencies much the same as your ear does in determining the noisiness of a sound. The unit used to indicate PNL is PNdB. The concept of effective perceived noise level (EPNL) is an extension of the PNL concept to include the effects of tone and duration. EPNL is a modification of PNL to include a tone weighting factor and a duration factor. The tone weighting factor varies both as a function of the

tone amplitude and its frequency. The duration factor indicates that the longer a sound is heard the noisier it is. The unit used to indicate EPNL is EPNdB.

Figure 6 defines the points under the flight path where both contractors present much of their noise results. These reference points are the same as those agreed upon by the FAA in their proposed noise certification rule for new aircraft. During approach the reference point is 1 nautical mile from the 50-foot obstacle under a 3^{o} glide slope. For take-off, the reference point under the flight path has been selected as 3.5 nautical miles from brake release. Although these points are the reference points, acoustic data were obtained along the flight path up to distances of about 4 miles from the end of the runway. In addition, data were taken to the side of the flight path to obtain better coverage of the noise field near the flight path. During take-off, measurements were taken at a side-line distance of 1500 feet to establish the reduction in side-line noise associated with the modification.

CONCLUDING REMARKS

The following papers will report on how successful the contractors have been in realizing the goal and objectives of the program. The contractor final reports will, in addition to the summary papers (papers 3 to 13) presented herein, also present detailed data that can be used in evaluating modifications to other engines on other airplanes. Information will also be presented that will provide a better understanding of acoustic materials and their application to noise problems.

REFERENCE

1. Anon.: Progress of NASA Research Related to Noise Alleviation of Large Subsonic Jet Aircraft. NASA SP-189, 1968.

TURBOFAN-ENGINE NOISE EMISSION

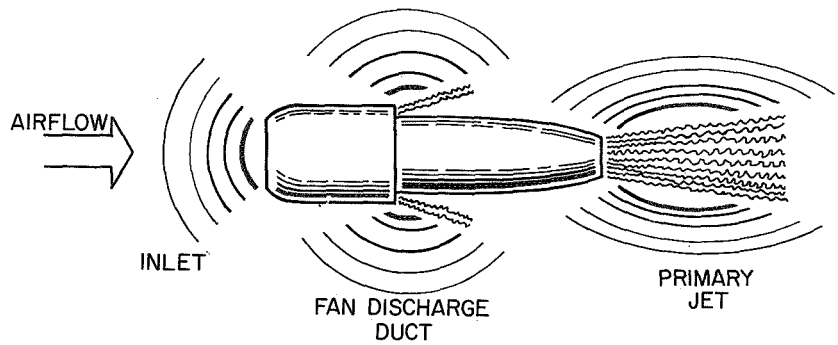

Figure 1

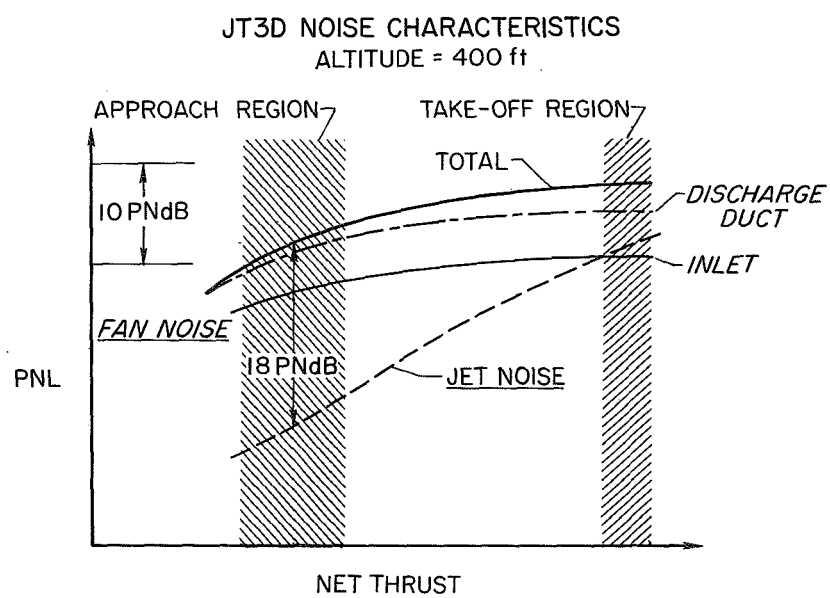

Figure 2

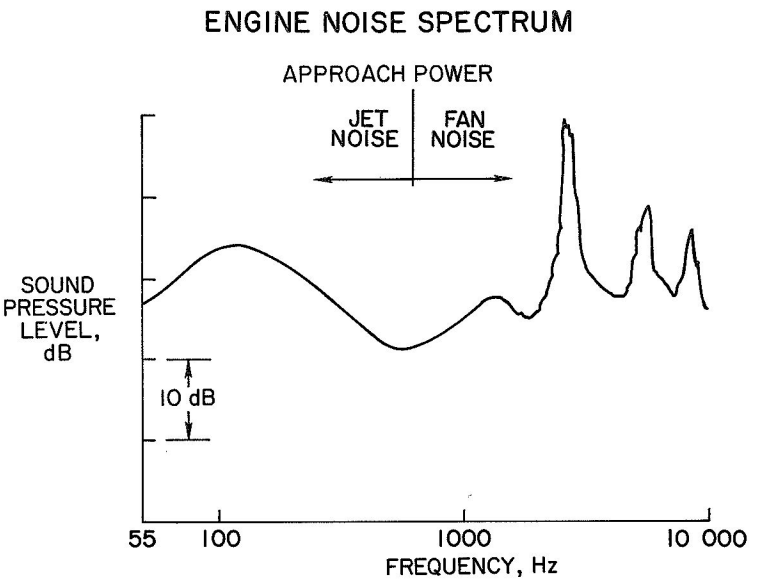

Figure 3

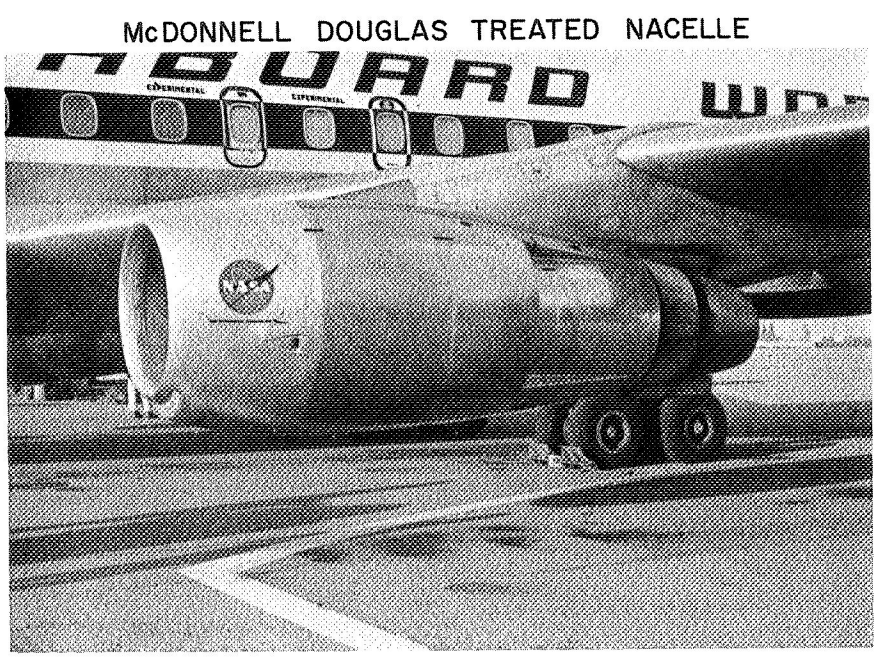

Figure 4

BOEING TREATED NACELLE

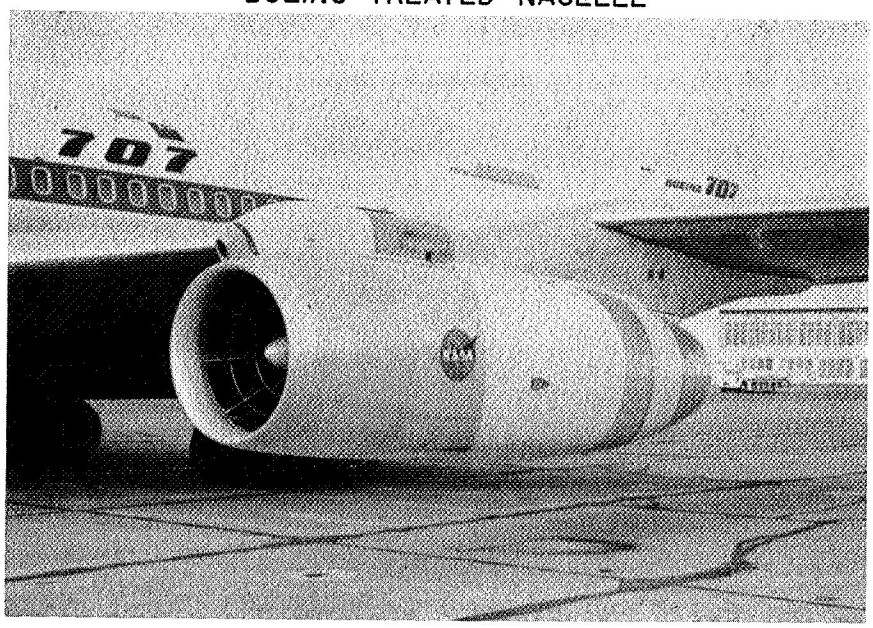

Figure 5

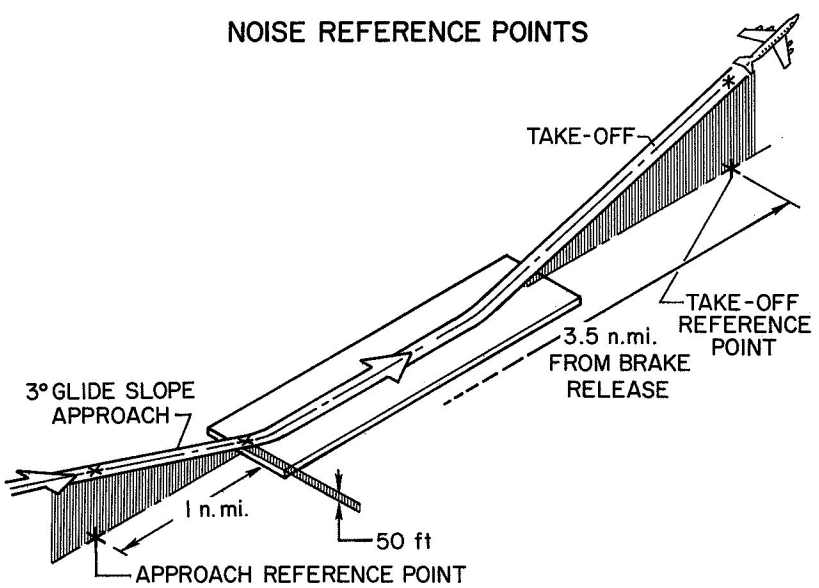

Figure 6